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Evaluation of Low-Tannin Grain Sorghum in Broiler Chicken Diets

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Abstract

Research trials were conducted to evaluate the effects of different levels of dietary grain sorghum on broiler live performance, carcass yield and shank (leg) and breast skin coloring. Iso-caloric diets were formulated where sorghum replaced corn at rates of 0% (control), 20, 40, 60, 80 and 100% for a total of 6 diets. For each of the two trials, 1500 Cobb 500 male broiler chicks were randomly allocated to 60 pens with 25 birds per pen (10 pens/diet) and grown to 46 days for the first research trial and 41 days for the second. There were no differences (P>.05) between treatments for livability and average weight on days 0, 14, 28 and 46/41 (for diets 1 through 6). For Trial 1 (T1), the 0-46 day adjusted feed conversion (FCR) was higher (P<.05) for the 100% grain sorghum diet as compared to 0, 40, 60 and 80% sorghum inclusion diets. For trial 2 (T2), only the 28-41 day adjusted feed conversion was significant with the 80 and 100% diets supporting higher feed conversions as compared to the other diets. No significant differences were seen in yield or abdominal fat in trial 1. For T2, selection weight for processing was heavier for the 0, 20, 60% diets as compared to the 40 and 100% sorghum diets and this trend carried through to the chilled carcass weight. Also in T2, leg quarters were heavier for the 20 and 40% diets as compared to the 60 and 80% diets and abdominal fat was heavier for the 0 and 40% diets as compared to the 80% diets. As dietary levels of sorghum increased, there was a linear decrease (P<0.05) in shank coloring scores as measured with the DSM color fan for both trials, with the 100% corn diets having the most yellow shanks and the 100% grain sorghum diets having the lightest colored shanks. Breast skin color evaluation post processing showed a similar trend (P=.0001) with the birds fed the 0 and 20% grain sorghum diets having the most yellow skins. Coloring steadily decreased as dietary grain sorghum increased with the 80 and 100% sorghum diets having the lightest breast skin coloring in both trials.

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Introduction

Poultry typically require their diet to contain a large percentage of cereal grains to provide protein and energy in their ration for optimal performance. The primary cereal grains used in poultry rations around the world include corn, wheat, barley, rice and sorghum or milo. Milo is produced in much smaller quantities than corn in the U.S. and is used in lesser quantities as a poultry feed ingredient since poultry are not grown in milo producing areas. However, milo is still the second most widely used cereal grain for commercial producers of broilers, turkeys, and egg layers in regions where both are produced in the U.S. Milo has the ability to grow in a wide variety climates ranging from marginal rainfall, poor soil composition to areas that experience waterlogging. These adaptations allow milo to grow in climates where very little environmental resources are needed and most crops would not thrive (Martin 1970, Walker 1999). The interest in milo is gradually increasing in sections of the world where feed and grain production is becoming exponentially scarce. As the world population continues to increase, crops such as milo will start to gradually become more economically and agriculturally important. In the past 50 years, the area planted with milo worldwide has increased by 60% and with yields increasing by 233%. This increase in milo production includes 51% fed to livestock and 49% for human consumption (Mauder, 2002).

The nutrient profile of milo is complementary to the protein sources typically used in formulation in poultry rations anywhere in the world and is very similar to corn when used as a replacement in diets .It has 95% of the digestible protein of corn. Amino acid digestibility compares favorably with corn, especially when considering newer milo varieties that are produced in the U.S today. The fat content of grain milo and the energy value for poultry is slightly lower as compared to corn, but this difference is easily balanced in rations with other sources of energy such as animal byproduct meals or oils. Compared to corn, grain milo contains reduced quantities of yellow xanthophyll that provide yellow coloring for egg yolk plus skin pigmentation in broilers. In some cases where lighter meat products are preferred by the customer, milo may be used to reduce carcass pigmentation for marketing advantages. Where color is required for some products, such as egg yolks that require intense pigmentation, other sources of pigments like marigold oil, yeast products, synthetic compounds and even corn based dried distillers grains are widely available and often can be included in rations on a least cost basis.

The ability to remove or greatly reduce the tannin component of sorghum has caused it to become much more of an interest to producers and growers. Sorghum planted in the U.S. for animal consumption contains only low- tannins. Tannins interfere with metabolism and absorption of nutrients plus their bitter taste reduces palatability. This reduction has greatly improved nutrient digestibility for poultry when fed sorghum based diets. Sorghum is used primarily in livestock and poultry feed in the United States and most foreign markets but in undeveloped countries like Africa, the Near East and Middle East, it has been utilized as food or as feed grains for centuries (Bello et. al. 1996 and Dogget 1970). Meat demand is expected to increase dramatically by 2020 thus creating a need to distribute and grow adequate grain supplies to feed to meat animals.

The following research trials were conducted to evaluate the effectiveness of low-tannin grain sorghum as an acceptable substitute for corn in a nutritionally balanced diet for growing broilers.

Literature Review

Grain Sorghum (Milo):

Sorghum or milo is indigenous to Africa and between 5,000 and 7,000 years ago it is thought to have originated in Ethiopia in the northeastern quadrant of Africa from the wild species S. arundina ceumsensulato. Evidence indicates that migrating tribes spread it to other countries in Africa before any records were established. The earliest available record of milo are carvings in the palace of Sennacherib, at Ninevah, Assyria, about 700B.C. In Ethiopia there were people of Caucasoid origin, speaking languages of the Cushitic subfamily of the Hamitic stock. Wild grain milo would have occurred as a weed in the cereal fields of the Cushites and it can still be found growing wild in these fields today. From Ethiopia, cultivated milo moved to West Africa at an early date, being carried across the Sudan to the region of the Upper Niger River. Here the Mande people developed a diversified agriculture and numerous varieties of milo were produced. The crop came to occupy a substantial area in West Africa during the Neolithic times (Dogget 1970, Walker 1970, Clark 1959, Hagerty 1941, Mauny 1953). Trade and shipping routes allowed it to reach India and Europe by the beginning of the Christian era and was mentioned by Pliny in the 1st century A.D., around 3000 years ago. The production of milo spread across Southern Asia via the silk routes and reached China apparently in the 13th century. It reached Bostwana by the 10th century A.D., Zambia by the 14th century, and southern Africa in the 16th century (Etuk et. al. 2012 and Walker, 1990). Milo eventually entered into America from West Africa with the slave trade around the mid-19th century and then it spread across the globe to areas that were suitable for its growth and development. Currently, this grain provides

43% of all major food staples in the originating section of Africa and this area has the greatest variability in wild and cultivated species of milo. (Etuk et. al. 2012 and Dogget 1970).

Sorghum bicolor (L.), is the fifth leading crop in the world following rice, corn, wheat and barley and third in the United States (Walker, 1990). Its protein content is higher than that of corn although its nutritional protein quality is lower (Dowling et al., 2002, Gualtieri and Rapaccini, 1990) In many parts of Africa and Asia grain milo is a basic food and it is the least known rising world crop among North Americans and Europeans. It is a principal source of alcoholic beverages in many countries and the plant frequently enters into the social patterns of tropic and sub-tropic nations. The stalks can frequently be seen carried as decorations in their marches during festivals and it is present on the national flag of Burundi, an East-African country (Dogget, 1970). In these areas it is described by several different names: in West Africa it is referred to as guinea-corn, South Africa- kafir corn, Sudan- durra, East Africa- mtama, India- juar, jowar, or cholam and in English publications it is sometimes referenced as the great millet. Most of the Chinese crops are known as kaoliang and in the Americas the term milo or milo maize is often used but, the sweet and juicy stems that produce syrup are referred to as sorgo. Milo is used primarily as livestock and poultry feed in the United States and most foreign markets but in undeveloped countries like Africa, the Near East and Middle East, it has been utilized as a food or as a feed grain for centuries (Bello et. al.1996 and Dogget, 1970). In the United States many people think of syrup when discussing grain milo instead of a livestock and poultry feed. In addition, it is becoming important in the industrial, import and export markets (Martin 1970). In the past 50 years, the area planted with milo worldwide has increased by 60% and the yield by 233% (Mauder, 2002). The total annual production ranges from 40-45 million tonnes from approximately 40 million hectares making grain milo one of the most important cereals in terms of production (ICRISAT, 2000). It has been reported that 51% of milo crops is used to feed livestock while 49% is for human food and other uses (Maunder, 2002). However according to Dowling et. al, only 48% of milo grain production is fed to livestock (2002).Between 1992-1994, Africa produced 27% of the world's total milo and the annual growth rate of area planted with milo was 3.7%, production 2.9% and yields 0.8% between 1977-1980. These figures demonstrate the importance that counties in Africa have placed on this grain. In the arid regions on Zimbabwe milo cultivation is being promoted as a cash crop and safety net for cultivators (Etuket. Al. 2012). In Nigeria it is produced almost solely by peasants and it has become a life source for these workers (Ega, et. al. 1992). According to Maunder (2002), milo could potentially offer the best opportunity to satisfy the doubling of meat demand in the developing world by 2020, as food for the poor, and as an alternative to corn. Conolly 2012 seems to agree that feed cost is expected to continue in the upward swing while broiler meat consumption increased by 43% between 1999 and 2009.

Grain Description, Appearance and Nutritive Value of Grain Sorghum:

Milo has the ability to adapt to a variety of different climates but it thrives in areas where the average summer temperature exceeds 20 degrees Celsius and the frost-free season is 125 days or more. It demonstrates the best results in areas where the average rainfall is between 400 mm and 600 mm per year which is too dry for corn to be grown successfully. Its morphological and physiological characteristics including extensive root systems, waxy bloom on the leaves are features in which help retain water and the ability to control its growth based on wet or dry conditions thus making milo a perfect crop to grow in drought prone areas (Walker 1999). The many varieties of milo exhibit considerable differences in plant and grain characteristics and physiological responses to environmental factors.

Milo can also grow in temperate and tropical areas up to 2300 meters in altitude and high rainfall by tolerating waterlogging (Martin 1970, Walker 1999, and Doggett 1970). Milo can be grown successfully on a wide range of soil types including tropical soil that is heavily rich in verstisols or dense clay where water content dramatically changes its volume and arid soils that consist mostly of sand. It can grow in soils where the pH ranges from 5.0-8.5 and is more tolerate to salinity than corn. Its adaptation to excel in poor soil allows it to produce grain under conditions where many other crops would fail (Martin 1970). Milo grain quality is affected by factors such as genotype, climate, soil type and fertilization, which affect the chemical composition and nutrient value (Walker 1999).

Milo is a standard type of grass that is generally grown as a single-stemmed variety but, it can show great variation in tillering or development of seed population capacity which is determined by genetic factors, plant spacing, soil moisture, soil fertility, photoperiod, plant vigor, and time. Certain varieties of milo will produce seeds after they flower. However, while they are flowering or extremely early in the season before they flower the plant might tiller or develop seeds as a response to damage. Varieties like milo and sudan grass groups typically have high seed production but, kafir and durra groups have significantly less seed production. Old plant bases can lead to some types of sorghum to reproduce for several years after the original crop but, most crops only produce annually. There is a large variation in milo height ranging from 45cm to over 4 meters. Shorter varieties usually have sections of the plant that produces the seeds or tillers that are taller than the main stem. However, the main stems on taller varieties usually grow higher than the tillers. Similarly, the stem thickness can also have a wide variation from a base diameter between 5mm to 3cm with a girth of 14.5 cm (Walker 1999 and Doggett 1970). Milo kernels can also share a wide range in size and weights that are classified as small

(8-10mg), medium (12-24mg) or large (25-35mg). The United States has chosen a commercial milo that is typically 4m long, 2mm wide and 2.5mm thick, with a kernel weight of 25-35mg. The kernel of milo is slightly smaller in size but, generally similar to that of corn. Whole milo grains can be given to sheep, pigs and even poultry but are usually ground for cattle. Obovoid, ellipsoid and orbicular are different shapes milo kernels can possess depending on the species of milo. These kernels consist of three unique anatomical components including a pericarp (outer layer), germ (embryo), and endosperm (storage tissue). Milo has different storage proteins but, the most abundant protein found is called kafirin. These proteins are prolamins which, are soluble in liquid alcohol with the presence of a reducing agent. Unfortunately, this storage protein is not digested well by broiler chickens and contains very small amounts of the necessary amino acid lysine. In broiler chicken diets it is important to have sufficient amounts of certain types of amino acids that these storage proteins are deficient in like threonine, tryptophan and lysine relative to corn. McDonald et al. (2000) reported that both corn and sorghum have the main limiting essential amino acids, arginine, lysine, methionine, cystine and tryptophan. Milo storage proteins are also very heterogeneous and have a surplus of leucine, proline and glutamic acid. As a result, when these protein proportions increase, the digestibility of these crucial amino acids declines (Selle et. al 2010, Watterson et al. 1993 and Sedghi et. al. 2012). During grain development these proteins are deposited predominately in the endosperm. Starch granules are surrounded by the developing protein bodies that inhibits access to amylases during digestion. Therefore, the kafirin concentration is a main factor in the quality and nutritional profile of milo (Chandrashekar and Kirleis, 1988). Kafirins account for up to 70% of the total protein content of milo and growers attempt to keep these proteins to a minimum through soil management and field crop production coupled with genetics (Hamaker et al., 1995). Whole grains of milo contain approximately 89 - 90% Dry Matter (DM) , 5.44 – 15% crude protein (CP), 2.8% ether extract (EE), 1.5 – 1.7% ash, 2.1 – 2.3% crude fiber (CF), and 71.7 – 72.3% nitrogen free extract (NFE) on an as fed basis (Ensminger and Olentine, 1978 and Ebadi et al., 2005). However, milo grain has 95% of the protein digestibility of corn and it is priced less in most markets (Adrian and Sayerse 1957, Pond et. al 1958 Sedghi et. al. 2012, Purseglove 1972 and Olomu, 1995). Xanthophyll, the pigment responsible for the yellowing of the skin, shanks and yolks of chickens and eggs, and linoleic acids are much lower in sorghum than in corn. Milo hybrids that contain yellow endosperms with carotene and xanthophylls increase the nutritive value of sorghum (Olomu, 1995). In addition, high- tannin milo has the lowest starch digestibility of all the cereal grains. The effect is caused by a resistance to digestibility by the hard peripheral endosperm layer (Rooney and Pflugfelder 1986). Unlike, wheat, barley and other “viscous” grains, milo and corn do not contain levels of NSPs (non-starch polysaccharides) which are a major cause of poor nutritional values. The crude fat in milo measures around 3% lower than the 4.6% average found in most corn varieties (Carter et. al. 1989).

In cereal-based diets more than 30% of the crude protein are contributed by proteins meaning that the quantity and nutritional quality of the protein play significant roles in broiler chicken diets (Dowling et al., 2002). The nutritive significance, cost and availability make milo the closest alternative feed ingredient to corn in poultry diets (Maunder, 2002). Nyannor, et al concluded that chick growth performance was equally supported by corn or sorghum (2007). Nutritionist worldwide have determined that low-tannin or tannin free sorghum is similar to corn in nutritional value for poultry. In the U.S only tannin free sorghum is grown so it can be used in poultry ration to maximize the nutritional value of the grain (Kriegshauser, et al. 2006).

Pelleting is also another factor that can affect the feed efficiency in poultry diets. Birds do not have the ability to masticate or chew their food so the size and quality of the pellet is essential in the amount of nutrients that the bird's consume. Unfortunately sorghum has a slightly lower energy value and it sometimes must be balanced in the feed with an additional oil or fat which decreases the pellet quality (Selle, et al 2010). Rodgers, et al. conducted a study using whole tannin-free sorghum and compared it to pelleted sorghum. They found that the birds fed whole sorghum performed equally well as the birds that were fed pelleted sorghum (2009). Another study conducted by Biggs and Parsons in 2009 which also found that whole sorghum added to a poultry diet at certain percentages combined with pelleted sorghum could increase the metabolizable energy and amino acid availability.

Tannins:

Tannins are a concern to nutritionists, production managers, purchasing agents, and feed mill managers when sorghum is used in poultry rations. Tannin-containing sorghums can be toxic and impair feed efficiency in poultry and swine. Therefore, it should not be used unless tannin levels and their nutritional consequences are well understood, and price is adequately equated with quality and risk. In addition, the pigment in the hulls of milo can cause skin staining during processing (Walker 1999). Four classes of milo are defined in the USA standards (USDA, 1999): "Sorghum," "Tannin sorghum", "White sorghum", and "Mixed sorghum." Within each class are four grades that differ in test weight, damaged kernels, broken kernels and foreign material. The "Sorghum" class cannot contain more than 3% "Tannin sorghum" and the pericarp may appear white, yellow, pink, orange, red or bronze. Similarly, the "White sorghum" class cannot contain more than 2% milo of other classes and the pericarp color appears white or translucent. These are the only 2 classes that are required to be virtually tannin free and they are the most widely used varieties in the United States' animal feed supply. The "Tannin sorghum" class contains at least 90% pigmented testa (seed cost) milo and the "Mixed sorghum" class may contain significant proportions of these tannin types. (Medugu et.al. 2012). Determine by the United State Grain Standards Act in 2005 commercial grain sorghum hybrids contain absolutely no tannins which, was achieved through rigorous sorghum breeding programs.   Therefore, when purchasing sorghum, buyers should specify US "sorghum" or "white sorghum" to avoid confusion about tannins and feeding values. Rapid qualitative tests can be used to determine tannin content if there are any issues that arise. There is a physical and a chemical method for reducing or removing the tannin content in milo. The physical methods of reducing or removing the tannins include, cooking, dehulling, autoclaving, toasting /roasting and soaking, while the chemical methods include, use of wood ash, addition of tallow, tannin binding agents, enzymes, germination and urea treatment. The choice of method will depend on their effectiveness in reducing tannin and the cost involved (Medugu et. al 2012).

Tannins can affect the utilization of milo's protein and metabolizable energy for poultry and this has caused sorghum to suffer from misconceptions and concerns about these toxic compounds (Boren and Waniska 1992). They have the ability to bind proteins and form insoluble or soluble tannin-protein complexes and also complex with starch, cellulose and minerals. They are responsible for the astringent taste of wine, unripe fruits, the colors seen in flowers and in autumn leaves. Tannins are usually subdivided into two groups, hydrolysable tannins and proanthocyanidins or condensed tannins. These condensed tannins are the most widely distributed (Walker 1999). Tannins can be toxic and affect the growth and development of broiler birds and they are present in sorghums with a pigmented seed cost or testa between the pericarp and endosperm. (teeter et. al. 1996, Martin 1970, Walker 1999 and Dogget 1970). The testa in tannin containing milo is colored by condensed tannins and grain colors are described as yellow, pink, orange, red, bronze and brown, the darker colors are associated with tannin containing milos (Walker 1999). The tannin content of milo is often thought to be closely related to darkness of seed color. Boren and Waniska determined that this was untrue and instead they determined that the color of the milo seed coat had no relevance on the amount of tannin content and other qualitative or/ and quantitative methods would need to be used to make an appropriate determination. The color of the different types of milo vary from pale yellow through various shades of red and brown to a deep purple brown (1992).

Xanthophyll:

In the United States the most widely used milo is white which, has a lack of xanthophyll the pigmentation that causes the yellowing of the skin and shanks in broilers chickens and the yellowing of yolks in eggs. This pigmentation is what most consumers associate the health and meat quality of the bird. The pigment is confined to the seed coat layer, with the exception of yellow, which can be present in the endosperm. (Fletcher et. al. 2000, Dog get 1970, Walker 1999). The different shades of skin and shank pigmentations are major factors that determine the selling price of live chickens among live broiler buyers. A darker shank color is preferred to one having a lighter shade of yellow. Aside from the type of feed the broiler was fed, the skin and shank color can be influenced by certain poultry diseases like coccidiosis and various types of respiratory infections. (Collin et. al. 1955). In addition, food appearance, particularly an intense bright coloration, is a very important characteristic that can determine product preference or rejection by the consumer. The pigments in yellow endosperm sorghum grain are xanthophyll and carotene. The most widespread group of food colorants belongs to the carotenoid family containing more than 600 pigments. Carotenoids were first discovered in carrots, from which in

1831, a compound named ‘beta-carotene’ was isolated. Broilers use these compounds for skin pigmentation, growth and fertility maintenance. There are various factors that have been found to affect pigment levels in the skin of poultry including, genetics, concentration and dietary source of pigments, health status of the birds, and scalding-plucking conditions during slaughtering, although other factors might play an important role. Unfortunately, milo does not contain a sufficient amount of this carotenoid to obtain the desirable yellow pigmentation on the skin and shank of poultry. Color can be assessed by the DSM Broiler Fan, expressed in a 101-110 scale, or by a colorimeter (Quinby and Schertz 1970, Palmer 1915, Garcia et. al. 2013, Collins et. al. 1955, Sirri et. al 2009 and Williams 1992). At present, corn is the only grain providing significant amounts of xanthophyll and carotenes in mixed feeds in the United States. However, milo varieties found in Nigeria and India with a yellow endosperm contains appreciable carotenoids and plant breeders in the United States are developing yellow endosperm types which contain larger amounts of carotenoids. (Wall and Blessin 1970). The common varieties of milo contained about 1.5 ppm total carotenoids, while crosses with yellow endosperm varieties contain as high as 10ppm. In contrast to yellow corn which contains 10 mg of biologically available xanthophyll per pound (lb) and 1500 international units (IU) per lb of vitamin A, milo grain contains only .5 mg per lb and 150 IU per lb, respectively. Pigmentation of broiler skin and egg yolks is a matter of consumer preference and the pigmenting value of yellow corn enhances its economic value especially in the United States and Mexico markets. The intensity of pigmentation in broilers is related mainly to the concentration in the diet, the daily feed intake and the length of the feeding period which would overall be the total amount of carotenoids consumed by the bird (Bartov and Bornstein 1961, Quisenberry and Tanksley Jr. 1970 and Castaneda et. al. 2005)

When consumers are buying fresh products, especially meat, visual appearance is the first and most important factor they will use in determining whether or not to purchase. In today's market, most fresh meat products are pre-packaged so the consumer doesn't have the ability to touch or smell the product and they are left to decide if it is healthy and fresh solely based on what they can visually perceive (Barbut 2001 and Williams 1995). Consumers will use their visual perception to assess several different aspects of fresh meat but the assessment of color will usually decide the freshness and quality of the meat even though it has little to no relevance (Barbut 2001). Skin color is a result of the type of feed eaten by the chicken, not a measure of nutritional value, flavor, tenderness, or fat content (USDA 2014). The measure of color in an extremely deep rooted emotion especially in consumers and the majority of the time it determines if they will or will not buy certain products. Even if this is un-rational, consumers are taught at very young ages that certain colors are directly correlated to taste, freshness and general overall quality of certain foods (Barbut 2001, Fields 2011 and Williams 1995). Consumer preferences are so strong that many are willing to pay premium prices for more yellow versus more pale skinned whole birds or cut-up parts with skin on even if there were no other differences between products. In the United States, an appreciation for highly pigmented poultry most likely reverts back to a time before confinement growing when flocks were allowed free access to green foliage causing the skin to become highly pigmented and was typically associated with a healthy bird. Immigrants seeking a new home in this country and settling in the northeast brought with them an affinity for yellow-skinned poultry instead of what they still refer to as "pale birds". These settlers had and continue to have the opinion that "yellow" is a measure of flocks with excellent health. However, currently the industry has developed and discovered that both highly pigmented birds and "pale" birds are equally healthy. However, flocks showing health problems do “bleach out” rapidly and consequently lose their rich, yellow coloring. Pigmentation must be regarded as a rule of thumb rather than as a fact when associated with the health of a flock. Yet, the preference remains strong for yellow skin, and knowledgeable poultry operators will deliver rather than resist consumer product preferences (Williams 1992). In the Mexican poultry industry, consumption of chicken with intense yellow skin and shanks is a deep-rooted cultural characteristic that defines product commercialization (Diaz et. al. 2012). The market is beginning to slightly shift away from highly pigmented birds as a result of the rising demand for further processed products like chicken nuggets. This is becoming more evident by the relative drop in the price of some feedstuffs that are used as sources of xanthophyll and by the fact that processors are not discriminating and complaining about poor pigmentation as much as in the past (Ratcliff et. al. 1961).

Evaluation of Low-Tannin Grain Sorghum in Broiler Chicken Diets

Trial 1

Materials:

This experiment was conducted following the Institution animal care user committee guidelines Low tannin grain sorghum was obtained from the 2013 harvest from the Division of Agriculture Research Station in Mariana, AR through Dr. Jason Kelley. Samples of the milo, corn and soybean meal were submitted to the University of Missouri lab for amino acid and proximate analysis and results are shown in Table 1. Overall the nutritional composition of the milo and corn was fairly similar. Dr. Park Waldroup at the University of Arkansas utilized this analysis to formulate a series of 6 dietary treatments in which milo replaced 0, 20, 40, 60, 80 and 100% of the dietary corn. Diets were formulated to meet or exceed standards for high producing males as suggested by Rostagno et al. (2011) and were formulated to be iso-caloric with similar amino acid content. The diet compositions and calculated nutrient value are shown in Tables 2-4. Nutrient analysis of the diets was in close agreement to calculated values shown in tables 5-7. Each dietary treatment was fed as a starter feed from 0-14 days of age, a grower feed from 14-28 days of age and then a finisher feed from 28-46 days of age. The diets were pelleted and the starter diet was crumbled. All diets contained a coccidostat to prevent protozoal coccidiosis but contained no growth promoting antibiotics. Each diet was fed to 10 replicate pens of 25 chicks. Each pen was equipped with a Choretime Revolution feed pan with 30 pound feed hopper and a Choretime nipple drinker line with 4 drinkers/line. Environmental conditions were controlled via a computerized system which relied on thermostats and an industry based temperature and minimum ventilation regime which allowed growing conditions during the project to closely mimic industry standards. Birds were checked a minimum of twice daily and any birds which died or were culled due to inability to reach feed and water were weighed and this weight used to calculate a weight adjusted feed conversion. The trial began November 17, 2013 and was completed on January 3, 2014.

Experimental Design:

The experimental design is shown in table 8. Fifteen hundred day-old male broiler Cobb 500 chicks (males from the female line) were obtained from the Cobb-Vantress Fayetteville, AR hatchery and had been vaccinated on day one at the hatchery for Mareks, Gumboro, Newcastle,and Bronchitis. The 25 chicks for each pen were randomly selected from 5 different chick boxes, group weighed by pen and then placed on used bedding material top dressed with kiln dried pine shavings. Lighting and temperature control followed industry standards and fans, inlets and heaters were used to maintain optimal growing conditions. Birds were group weighed by pen on days 0, 14, 28, and 46. Feed consumption was measured for each period by weighing all feed added to the pens and any remaining feed at weigh days. Birds were checked twice daily for mortality and any dead birds were weighed and recorded on a pen sheet and in a log book. Feed conversion was calculated for each period by dividing total feed used by total live weight of the birds in each pen. Mortality weight for each period was added to the pen live weight prior to dividing this combined weight into the feed consumed weight for calculation of an adjusted feed conversion. At day 46, five birds showing no signs of abnormalities including leg disorders were randomly selected, individually weighed, wing banded in both wings and marked with spray paint for easy identification for the following day processing. During the selection process, each bird was individually evaluated for pigmentation coloring of the shanks or legs. A DSM color fan ranging from pale yellow- cream (color 101) to deep orange (color 108) was used for the evaluation and all color evaluations were done by one individual for consistency of measurement. After an 8 hour feed withdrawal, birds were placed in coops and transported to the University of Arkansas processing plant. Birds were again individually weighed, placed on shackles, stunned with an electrical water bath, bled out, scalded, de-feathered, and then eviscerated. .During the evisceration process, the leaf fat was carefully removed from the abdominal and gizzard area. The WOG (carcass without giblets) was weighed as well as the fat and then the WOG was placed into an ice bath for a 2 hour chilling process. Next the carcass was removed from the ice bath, re-weighed and then cut into breast fillets, tenders, wings and leg quarters. Each part was weighed post cut-up. Yield was determined by dividing the carcass weight by the slaughter weight and multiplying by 100. Percent abdominal fat was calculated as a percent of the slaughter weight. Parts yield was determined as both a percent of the carcass and of the slaughter weight.

Results were analyzed using the GLM procedure of SAS and statistically significant means (P<.050 were separated using the least square means (LSMeans) repeated t-test). The pen served as the experimental unit for the live production data and the individual bird was the experimental unit for the processing data.

Due to the continued shift by the broiler industry to grow meat birds to a heavier market weight to achieve more pounds of meat processed per shackle space, it was decided to increase the grow-out period from 0-42 to 0-46 days and adjust the number of replications from 12 to 10 to assure adequate funding for covering feed costs for the additional 4 days of grow-out. This would provide data during the critical late stage of grow-out when broilers experience the most significant rate of development of breast meat and would therefore be most impacted by dietary essential amino acid or energy deficiencies.

Table 1. Nutrient Analysis of Primary Ingredients

Nutrient	Milo	Corn	Soy
	Weight/weight %		
Taurine	0.16	0.16	0.102
Hydroxyproline	.01	0.03	0.06
Aspartic Acid	.55	0.75	5.00
Threonine	.27	0.33	1.64
Serine	.35	0.39	1.74
Glutamic Acid	1.61	1.69	7.61
Proline	.61	0.75	2.19
Lanthionine	0.0	0.00	0.00
Glycine	.30	0.39	1.88
Alanine	.72	0.69	1.94
Cysteine	.14	0.19	0.65
Valine	.42	0.48	2.15
Methionine	.14	0.21	0.63
Isoleucine	.33	0.37	2.11
Leucine	1.04	1.09	3.44
Tyrosine	.24	0.33	1.69
Phenyl alanine	.42	0.47	2.25
Hydroxylysine	.01	0.02	0.05
Ornithine	0.0	0.00	0.04
Lysine	.22	0.37	2.80
Histidine	.19	0.27	1.15
Arginine	.33	0.50	3.16
Tryptophan	.06	0.08	0.62
Total	8.14	9.56	42.92
Crude Protein	8.00	10.21	44.35
Moisture	11.57	NA	NA
Crude Fat	3.47	NA	NA
Crude Fiber	2.36	NA	NA
Ash	1.48	NA	NA

Table 2. Composition (g/kg) and calculated nutrient content of broiler starter diets* (0 to 14 d) formulated to contain different levels of grain sorghum as percentage of total grain component.

Ingredient	Grain sorghum % of total grain					
	0 (T_1)	**20 (T_2)**	**40 (T_3)**	**60 (T_4)**	**80 (T_5)**	**100 (T_6)**
Yellow corn	607.45	474.30	347.28	226.28	110.60	0.00
Grain sorghum	0.00	118.57	231.58	339.42	442.42	540.90
Soybean meal	338.42	349.09	359.27	368.98	378.25	387.12
Poultry oil	14.80	19.01	23.02	26.85	30.50	34.01
Limestone	9.04	8.87	8.71	8.55	8.40	8.27
Dicalcium phosphate	17.59	17.47	17.37	17.26	17.17	17.07
Salt	4.37	4.34	4.30	4.27	4.25	4.22
DL-Methionine	2.69	2.76	2.82	2.89	2.95	3.00
L-Lysine HCl	2.10	2.08	2.06	2.04	2.02	2.00
L-Threonine	1.29	1.26	1.24	1.21	1.19	1.16
2X vitamin premix[1]	0.25	0.25	0.25	0.25	0.25	0.25
Mintrex P_Se[2]	0.50	0.50	0.50	0.50	0.50	0.50
Choline Cl 60%	1.00	1.00	1.00	1.00	1.00	1.00
Coban 90[3]	0.50	0.50	0.50	0.50	0.50	0.50
TOTAL	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
Calculated analysis						
Crude protein, %	21.77	21.83	21.89	21.94	21.99	22.04
Calcium, %	0.91	0.91	0.91	0.91	0.91	0.91
Nonphytate P, %	0.45	0.45	0.45	0.45	0.45	0.45
ME, kcal/kg	3085.00	3085.00	3085.00	3085.00	3085.00	3085.00
Lysine, %	1.34	1.34	1.34	1.34	1.34	1.34

[1]Provides per kg of diet: vitamin A 7715 IU; cholecalciferol 5511 IU; vitamin E 16.53 IU; vitamin B_{12} 0.013 mcg; riboflavin 6.6 mg; niacin 39 mg; pantothenic acid 10 mg; menadione 1.5 mg; folic acid 0.9 mg; thiamin 1.54 mg; pyridoxine 2.76 mg; d-biotin 0.66 mg; ethoxyquin 125 mg.
[2]Provides per kg of diet: Mn (as manganese methionine hydroxy analogue complex) 40 mg; Zn (as zinc methionine hydroxy analogue complex) 40 mg; Cu (as copper methionine hydroxy analogue complex) 20 mg; Se (as selenium yeast) 0.3 mg. Novus International, St. Louis MO.
[3]Elanco Animal Health Division of Eli Lilly and Co., Indianapolis IN 46825.

Table 3. Composition (g/kg) and calculated nutrient content of broiler grower diets* (14 to 28 d) formulated with with different levels of grain sorghum as percentage of total grain component.

Ingredient	**Grain sorghum % of total grain**					
	0 (T_1)	**20 (T_2)**	**40 (T_3)**	**60 (T_4)**	**80 (T_5)**	**100 (T_6)**
Yellow corn	679.95	530.88	388.83	253.28	123.80	0.00
Grain sorghum	0.00	132.73	259.22	379.92	495.21	605.45
Soybean meal	281.47	293.42	304.81	315.68	326.06	335.98
Poultry oil	2.45	7.17	11.66	15.95	20.05	23.95
Limestone	8.62	8.43	8.25	8.08	7.91	7.75
Dicalcium phosphate	15.47	15.35	15.23	15.11	15.00	14.90
Salt	4.40	4.36	4.32	4.29	4.26	4.23
DL-Methionine	2.26	2.34	2.41	2.48	2.55	2.62
L-Lysine HCl	2.05	2.02	2.00	1.97	1.95	1.93
L-Threonine	1.08	1.05	1.02	0.99	0.96	0.94
2X vitamin premix[1]	0.25	0.25	0.25	0.25	0.25	0.25
Mintrex P_Se[2]	0.50	0.50	0.50	0.50	0.50	0.50
Choline Cl 60%	1.00	1.00	1.00	1.00	1.00	1.00
Coban 90[3]	0.50	0.50	0.50	0.50	0.50	0.50
TOTAL	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
Calculated analysis						
Crude protein, %	19.92	19.99	20.05	20.11	20.17	20.23
Calcium, %	0.82	0.82	0.82	0.82	0.82	0.82
Nonphytate P, %	0.41	0.41	0.41	0.41	0.41	0.41
ME, kcal/kg	3085.00	3085.00	3085.00	3085.00	3085.00	3085.00
Lysine, %	1.20	1.20	1.20	1.20	1.20	1.20

[1]Provides per kg of diet: vitamin A 7715 IU; cholecalciferol 5511 IU; vitamin E 16.53 IU; vitamin B_{12} 0.013 mcg; riboflavin 6.6 mg; niacin 39 mg; pantothenic acid 10 mg; menadione 1.5 mg; folic acid 0.9 mg; thiamin 1.54 mg; pyridoxine 2.76 mg; d-biotin 0.66 mg; ethoxyquin 125 mg.
[2]Provides per kg of diet: Mn (as manganese methionine hydroxy analogue complex) 40 mg; Zn (as zinc methionine hydroxy analogue complex) 40 mg; Cu (as copper methionine hydroxy analogue complex) 20 mg; Se (as selenium yeast) 0.3 mg. Novus International, St. Louis MO.
[3]Elanco Animal Health Division of Eli Lilly and Co., Indianapolis IN 46825.

Table 4. Composition (g/kg) and calculated nutrient content of broiler finisher diets* (28 to 46 d) formulated with different levels of grain sorghum as percentage of total grain component.

Ingredient	Grain sorghum % of total grain					
	0 (T_1)	**20 (T_2)**	**40 (T_3)**	**60 (T_4)**	**80 (T_5)**	**100 (T_6)**
Yellow corn	633.92	496.47	364.28	237.28	115.98	0.00
Grain sorghum	0.00	124.12	242.85	355.92	463.94	567.20
Soybean meal	312.42	321.84	331.48	341.68	351.40	360.70
Poultry oil	19.85	23.96	28.00	32.02	35.86	39.52
Limestone	7.72	7.56	7.40	7.25	7.09	6.95
Dicalcium phosphate	13.80	13.69	13.59	13.48	13.38	13.28
Salt	4.39	4.36	4.33	4.29	4.26	4.24
DL-Methionine	2.52	2.61	2.68	2.75	2.81	2.87
L-Lysine HCl	1.98	2.01	2.02	1.99	1.97	1.95
L-Threonine	1.15	1.13	1.12	1.09	1.06	1.04
2X vitamin premix[1]	0.25	0.25	0.25	0.25	0.25	0.25
Mintrex P_Se[2]	0.50	0.50	0.50	0.50	0.50	0.50
Choline Cl 60%	1.00	1.00	1.00	1.00	1.00	1.00
Coban 90[3]	0.50	0.50	0.50	0.50	0.50	0.50
TOTAL	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
Calculated analysis						
Crude protein, %	20.85	20.86	20.89	20.95	21.00	21.05
Calcium, %	0.76	0.76	0.76	0.76	0.76	0.76
Nonphytate P, %	0.38	0.38	0.38	0.38	0.38	0.38
ME, kcal/kg	3151.75	3151.75	3151.75	3151.75	3151.75	3151.75
Lysine, %	1.27	1.27	1.26	1.26	1.26	1.26

[1]Provides per kg of diet: vitamin A 7715 IU; cholecalciferol 5511 IU; vitamin E 16.53 IU; vitamin B_{12} 0.013 mcg; riboflavin 6.6 mg; niacin 39 mg; pantothenic acid 10 mg; menadione 1.5 mg; folic acid 0.9 mg; thiamin 1.54 mg; pyridoxine 2.76 mg; d-biotin 0.66 mg; ethoxyquin 125 mg.
[2]Provides per kg of diet: Mn (as manganese methionine hydroxy analogue complex) 40 mg; Zn (as zinc methionine hydroxy analogue complex) 40 mg; Cu (as copper methionine hydroxy analogue complex) 20 mg; Se (as selenium yeast) 0.3 mg. Novus International, St. Louis MO.
[3]Elanco Animal Health Division of Eli Lilly and Co., Indianapolis IN 46825.

Table 5. Analyzed nutrient composition of starter diets (0-14 d of age)

	Dietary Treatments					
	T_1	T_2	T_3	T_4	T_5	T_6
	----------(%)----------					
	Analyzed Nutrient Composition					
Moisture (%)	11.1	11.1	12.0	12.1	11.6	12.4
Crude Protein (%)	20.4	21.5	18.9	18.4	18.3	17.7
Crude Fat (%)	3.02	4.46	3.33	4.11	4.72	4.72
Ash (%)	5.45	5.97	5.10	5.63	5.65	5.32

Table 6. Analyzed nutrient composition of Grower Diets (14-28 days of Age)

	Dietary Treatments					
	T_1	T_2	T_3	T_4	T_5	T_6
	------------------------(%)------------------------					
	Analyzed Nutrient Composition					
Moisture (%)	11.6	11.7	11.6	11.4	11.3	11.5
Crude Protein (%)	20.4	18.9	20.1	20.5	20.8	21.0
Crude Fat (%)	4.49	5.27	5.76	6.40	7.15	8.03
Ash (%)	5.17	5.01	5.02	5.23	4.90	5.17

Table 7. Analyzed Nutrient Composition of Finisher Diets (28-46 days of Age)

	Dietary Treatments					
	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**
	---------------------------------(%)---------------------------------					
	Analyzed Nutrient Composition					
Moisture (%)	15.2	15.0	14.4	14.1	13.2	13.1
Crude Protein (%)	20.9	21.0	22.0	20.4	21.5	21.4
Crude Fat (%)	4.1	4.6	4.4	5.3	5.4	5.5
Ash (%)	4.3	4.3	4.6	4.7	4.3	4.0

Table 8. Experimental Design

TRT	Corn (%)	Milo (%)	No. of pens/trt	No. of birds/pen
1	100	0	10	25
2	80	20	10	25
3	60	40	10	25
4	40	60	10	25
5	20	80	10	25
6	0	100	10	25

Results:

Average Body Weight and Feed Conversion Results:

The results for average weights, feed efficiency and livability are shown in Tables 9- 18. Waiting for the cooler weather paid off extraordinarily with birds across all treatments reaching an amazing average weight of almost 8 pounds in 46 days with a .170 pound average daily gain. The results shown in Table 9 show that all treatments started with similar average chick weights (46 grams, P>.05) and this helped assure a statistically sound comparison of the dietary treatments. At days 14, 28 and 46, all treatments had similar average weights (P>.05) with birds finishing a pound heavier than the commercial flock at the Applied Broiler Research Farm (ABRF) (7.80 versus 6.80 lbs) which marketed as a straight run flock at 46 days of age during a similar time frame. Increasing levels of grain sorghum clearly did not inhibit bird consumption of feed and readily supported the genetic growth rate potential. The unadjusted feed-to-gain ratios (pound of feed per pound of gain) as well as feed intake (Tables 11 and 13) were also not significantly impacted by increasing levels of grain sorghum. However, when feed conversion were adjusted using mortality weight (Table 12), there were statistical differences at day 28 and 46. At day 28, the highest or most inefficient feed conversion was seen with the 100% corn diet 1.471 and all of the grain sorghum diets were better (1.443 for the 80% diet to 1.465 for the 100% grain sorghum diet, P value =.0468) For the day 46 un-adjusted feed conversion, the best conversion was seen with the 100% corn, 60 and 80% grain sorghum diets (1.72, 1.72, 1.71, respectively) and the lowest feed conversion was seen with the 100% sorghum diet which was similar to the 20 and 40% sorghum diets (1.75, 1.74 and 1.73, respectively, P=.851). This indicates that complete replacement of corn with grain sorghum may increase feed conversion when broilers are grown to heavier weights. It also indicates that the estimated available energy in sorghum may be slightly overestimated.

Livability:

Livability was excellent across all treatments, ranging from 96.80% to 99.60% and there were no statistical differences between the treatments (Table 14).

Processing:

Yield analysis also showed that there were no differences in average selection weights, pre- slaughter weights, pre-chill WOG (without giblets) weight, post-chill WOG weights, dressing or yield percent or abdominal fat pad weight or as a percent of the live weight (Tables 15-17). Figure 1 shows the DSM Broiler Fan used for the evaluation of pigmentation of the skin on the shanks (legs) and of the breast skin post processing. The shanks were statistically impacted by the dietary levels of grain sorghum and as levels increased, there was a linear decrease in pigmentation (Table 18). Values ranged from a high of 104.24 for the 100% corn diet to a low of 101.12 for the 100% grain sorghum diet. The color relationship was not as clearly defined for the evaluation of the skin on the breast of processed carcasses prior to chilling with the 100% corn (0% sorghum) and 20% grain sorghum diets having similar scores of 102.57 and 102.48, the 40 and 60% grain sorghum diets having similar scores of 102.2 and 101.98 and the 80 and 100% sorghum diets having similar scores, the lowest, at 101.44 and 101.4 (P=.0001).

Table 9. Average body weight (Mean ± SEM) of male broilers fed different levels milo/sorghum in feed to 46 days of age

Trt	Day 0	Day 14	Day 28	Day 46
	------------------------------kg-----------------------			
1- Corn	.0462 ± .0002	0.491 ± .0038	1.659 ± .0176	3.559 ± .0245
2-20% Sorghum	.0467± .0003	0.489 ± .0005	1.648 ± .0133	3.539 ± .0209
3-40% Sorghum	.0465 ± .0002	0.495 ± .0003	1.675 ± .0151	3.558 ± .0274
4-60% Sorghum	.0461 ± .0046	0.498 ± .0045	1.689 ± .0141	3.618 ± .0304
5-80% Sorghum	.0467 ± .0002	0.493 ± .0028	1.679 ± .0087	3.623 ± .0200
6-100% Sorghum	.0465 ± .002	0.502 ± .0028	1.676 ± .0087	3.578 ± .0200
P-value	.2235	0.1898	0.3425	0.1257

Table 10. Average body weight Gain (Mean ± SEM) of male broilers fed different levels of milo/sorghum in feed to 46 days of age

Trt	Day 0-14	Day 14-28	Day 0-28	Day 28-46	Day 0-46
---------------------------kg-----------------------					
1-Corn	0.445± 0.004	1.167± .0148	1.614± 0.178	1.900 ± 0.002	3.513± 0.024
2-20% Sorghum	0.443 ± 0.005	1.158 ± 0.010	1.601 ± 0.013	1.892 ± 0.018	3.493 ± 0.179
3-40% Sorghum	0.449 ± 0.003	1.178 ± 0.014	1.627 ± 0.015	1.885 ± 0.021	3.511 ± 0.027
4-60% Sorghum	0.452 ± 0.005	1.191 ± 0.011	1.643 ± 0.014	1.929 ± 0.022	3.572 ± 0.030
5-80% Sorghum	0.446 ± 0.003	1.186 ± 0.009	1.632 ± 0.009	1.945 ± 0.153	3.577 ± 0.200
6-100% Sorghum	0.455 ± 0.020	1.175 ±0.010	1.630 ± 0.012	1.901 ± 0.241	3.531 ± 0.028
P-value	0.1778	0.4175	0.3360	0.2643	0.1236

Table 11. Un-adjusted feed conversion (Mean ± SEM) of male broilers grown to 46 days of age and fed different levels of dietary milo/sorghum*

Trt	Day 0-14	Day 14-28	Day 0-28	Day 28-46	Day 0-46
			--------------------------kg:kg---------------------------		
1-Corn	1.31 ± .011	1.60 ± .011	1.52 ± .008	1.89 ± .019	1.72± .01
2-20% Sorghum	1.31 ± .011	1.57 ± .011	1.50 ± .008	1.93 ± .019	1.73± .01
3-40% Sorghum	1.29 ± .011	1.58 ± .011	1.50 ± .008	1.94 ± .019	1.73± .01
4-60% Sorghum	1.30 ± .011	1.59 ± .011	1.51 ± .008	1.89 ± .019	1.72± .01
5-80% Sorghum	1.30 ± .011	1.57 ± .011	1.49 ± .008	1.90 ± .019	1.71± .01
6-100% Sorghum	1.32 ± .011	1.59 ± .011	1.52 ± .0086	1.95 ± .019	1.75± .01
P-value	0.5288	0.2236	0.1366	0.1209	0.2102

*Means within a column with no common superscript differ significantly ($P < 0.05$).

Table 12. Average Feed Conversion Ratio (Mean ± SEM) of male broilers grown to 46 days of age and fed different levels of dietary milo/sorghum*

Trt	Day 0-14	Day 14-28	Day 0-28	Day 28-46	Day 0-46
			----------------------------------kg:kg-----------------------------		
1-Corn	1.31± .011	1.59 ± .011	1.52 ±. 008	1.87± .015	1.71b ± .008
2-20% Sorghum	1.31 ± .011	1.57 ± .011	1.50 ± .008	1.92 ± .043	1.72ab ± .008
3-40% Sorghum	1.29 ± .011	1.58 ± .011	1.50 ± .008	1.90 ± .043	1.71b± .008
4-60% Sorghum	1.29 ± .011	1.57 ± .008	1.51 ± .008	1.89 ± .044	1.71b ± .008
5-80% Grain Sorghum	1.29 ± .011	1.56 ± .011	1.49 ± .006	1.89 ± .042	1.70b ± .008
6-100% Grain Sorghum	1.30 ± .011	1.59 ± .011	1.52 ± .007	1.95 ± .042	1.744a ± .011
P-value	0.6350	0.0822	0.2236	0.0901	0.0125

*Feed conversions have been adjusted by adding mortality to the live bird weight so that total pounds gained on feed consumed is calculated
*Numbers in the same column with different letters are statistically different

Table 13. Impact of increasing levels of dietary grain sorghum on the average feed intake of male broiler chickens grown to 46 days of age and fed different levels of dietary grain sorghum/milo

Trt	Day 0-14	Day 14-28	Day 0-28	Day 28-46	Day 0-46
---------------------------kg:kg---------------------------					
1-Corn	.580 ± .005	1.862 ± .016	2.441± .019	3.558± .03	5.998± .04
2-20% Sorghum	.578± .005	1.812 ± .016	2.390 ± .019	3.634 ± .03	6.017± .04
3-40% Sorghum	.578± .005	1.855 ± .016	2.433 ± .019	3.587 ± .03	6.019± .04
4-60% Sorghum	.583± .005	1.874 ± .016	2.456 ± .019	3.650 ± .03	6.103± .04
5-80% Sorghum	574± .005	1.851 ± .016	2.424 ± .019	3.669 ± .03	6.091± .04
6-100% Sorghum	.593 ± .005	1.866± .016	2.457 ± .019	3.704 ± .03	6.155± .04
P-value	0.3043	0.1394	0.1615	0.0681	0.0563

*Average feed intake calculated for each period by multiplying the weight gain by the adjusted feed conversion

Table 14. Impact of increasing dietary levels of grain sorghum on livability of male broilers fed to 46 days of age

Treatment	Days 0-14	Days 0-28	Days 0-46
		------------------------------%--------------------------	
1-Corn	99.60± 0.40	99.20± 0.53	98.80± 0.85
2-20% Sorghum	99.60± 0.40	99.60± 0.40	98.00± 0.89
3-40% Sorghum	98.00± 0.67	97.60± 0.88	96.80± 0.10
4-60% Sorghum	98.40± 0.86	96.80± 1.44	96.80± 1.44
5-80% Sorghum	98.00± 0.89	97.20± 0.85	96.80± 0.10
6-100% Sorghum	98.00± 1.07	99.60± 1.07	97.20± 1.041
P-value	.3780	.2085	.6857

Table 15. Average processing weights (Mean ± SEM) of 46 day old male broilers fed different levels of Sorghum/Milo*

Trt	Selection Weight	Pre-slaughter Weights	Pre-chill Weights	Post-Chill Weights
		------------------------kg-----------------------		
1-Corn	3.67 ± .317	3.62 ± .345	2.71 ± .280	2.77 ± .294
2-20% Sorghum	3.57 ± .277	3.57 ± .276	2.66 ± .234	2.70 ± .2230
3-40% Sorghum	3.59 ± .342	3.60 ± .360	2.71 ± .292	2.75 ± .304
4-60% Sorghum	3.68 ± .265	3.63 ± .261	2.73 ± .229	2.78 ± .236
5-80% Sorghum	3.65 ± .299	3.64 ± .292	2.73 ± .253	2.78 ± .244
6-100% Sorghum	3.62 ± .303	3.63± .303	2.72 ± .233	2.77 ± .236
P-value	.0689	0.6118	0.4388	0.2576

*Means within a column with no common superscript differ significantly (P < 0.05).

Table 16. Average parts weight (Mean ± SEM) of 46 day old male broilers fed different levels of dietary Sorghum/Milo*

Trt	Breast Weight	Tenders Weight	Wings Weight	Legs Weight	Fat Weight
			-------------------------kg --------------------------		
1-Corn	.754 ± .012	.158 ± .003	.273 ± .003	.842 ± .011	.055 ± .002
2- 20% Sorghum	.735 ± .012	.149 ±.002	.271 ± .003	.820 ± .009	.055± .002
3-40% Sorghum	.756 ± .014	.150.± .003	.273 ± .003	.839 ± .009	.050 ± .002
4- 60% Sorghum	.761± .012	.157 ± .002	.274. ± .002	.834 ± .009	.050 ± .002
5- 80% Sorghum	.765 ± .013	.154 ± .002	.269 ± .002	.839 ± .009	.050 ± .002
6- 100% Sorghum	.769 ± .012	.154 ± .002	.271 ± .008	.839 ± .008	.050 ± .002
P-value	.4065	.0646	.7690	.6672	.2045

*Means within a column with no common superscript differ significantly (P < 0.05).

Table 17. Average carcass and parts yield (Mean ± SEM) of 46 day old male broilers fed different dietary levels of Sorghum/Milo*

Trt	Carcass Yield	Breast Yield	Tenders Yield	Wings Yield	Fat Yield	Legs Yield
			-------------------------%----------------------			
1-Corn	75.0 ± 0.30	27.2 ± 0.25	5.7 ± 0.07	9.9 ± 0.07	2.1 ± 0.07	30.43± 2.75
2-20% Sorghum	74.7 ± 0.20	27.1 ± 0.30	5.5 ± 0.07	10.0 ± .10	2.1 ± 0.09	30.3 ± 0.19
3- 40% Sorghum	75.2 ± 0.21	27.6 ± 0.31	5.5 ± 0.07	9.9 ± 0.07	1.9 ± 0.08	30.5 ± 0. 20
4-60% Sorghum	75.0 ± 0.22	27.4 ± 0.32	5.7 ± 0.06	9.9 ± 0.06	1.9 ± 0.07	30.1 ± 0.20
5-80% Sorghum	75.0 ± 0.20	75.0 ± 0.20	5.60 ± 0.07	9.7 ± 0.07	1.9 ± 0.08	30.3 ± 0.25
6-100% Sorghum	75.1 ± 0.39	27.8 ± 0.29	5.6 ± 0.06	9.8 ± 0.07	1.9 ± 0.08	30.4 ± 7.50
P-value	0.9188	0.6241	0.0673	0.0694	0.1287	0.7907

*Means within a column with no common superscript differ significantly (P < 0.05).

Table 18. Impact of increasing dietary levels of grain sorghum on shank and skin pigmentation of male broiler chickens at 46 days of age

Treatment	**Shank Score /SEM**	**Breast Skin Color Score /SEM**
1-Corn Diet	104.24a ± 0.113	102.57a ± 0.127
2-20% Grain Sorghum	103.78b ± 0.108	102.49a ± 0.128
3- 40% Grain Sorghum	103.00c ± 0.070	102.02b ± 0.123
4-60% Grain Sorghum	102.35d ± 0.086	101.98b ± 0.088
5-80% Grain Sorghum	101.62e ± 0.05	101.44c ± 0.088
6-100% Grain Sorghum	101.12f ± 0.05	101.40c ± 0.076
P-value	.001	.0001

Figure 1. DSM Broiler Fan utilized for evaluation of shank (live bird legs) and breast skin (post processing) pigmentation.

Evaluation of Low-Tannin Grain Sorghum in Broiler Chicken Diets

Trial 2

Materials and Methods:

This experiment was conducted following the Institution animal care user committee guidelines. Low tannin grain sorghum was obtained from the 2013 harvest from the Division of Agriculture Research Station in Mariana, AR through Dr. Jason Kelley. Samples of the milo, corn and soybean meal were submitted to the University of Missouri lab for amino acid and proximate analysis and results are shown in Table 1 of trial 1. Overall the nutritional composition of the milo and corn was fairly similar. Dr. Park Waldroup (University of Arkansas Professor, retired) utilized this analysis to formulate a series of 6 dietary treatments were formulated based on the analyzed nutrient content in which milo replaced 0, 20, 40, 60, 80 and 100% of the dietary corn. In this series, the metabolizable energy value assigned to sorghum in the formulation was slightly adjusted down as compared to the previous trial. Diets were formulated to meet or exceed standards for high producing males as suggested by Rostagno et al. (2011) and were formulated to be iso-caloric with similar amino acid content. The diet compositions and calculated nutrient value for the starter, grower, and finisher diets are shown in Tables 1-3. Nutrient analysis of the diets were in close agreement to the calculated values shown in Tables 4-6. Each dietary treatment was fed as a starter feed from 0-14 days of age, a grower feed from 14-28 days of age and then a finisher feed from 28-41 days of age. The diets were pelleted and the starter diet was crumbled. All diets contained a coccidostat to prevent protozoal coccidiosis but contained no growth promoting levels of antibiotics. Each diet was fed to 10 replicate pens of 25 chicks. Each pen was equipped with a Choretime Revolution feed pan with 30 pound feed hopper and a Choretime nipple drinker line with 4 drinkers/line. Environmental conditions were controlled via a computerized system which relied on thermostats and an industry based temperature and minimum ventilation regime which allowed growing conditions during the project to closely mimic industry standards. Birds were checked a minimum of twice daily and any birds which died or were culled due to inability to reach feed and water were weighed and this weight used to calculate a weight adjusted feed conversion.

Experimental Design:

The experimental design is shown in Table 7. Fifteen hundred day-old male broiler Cobb 500 chicks (males from the female line) were obtained from the Cobb-Vantress Fayetteville, AR hatchery and had been vaccinated on day one at the hatchery for Mareks, Gumboro, Newcastle, and Bronchitis. The 25 chicks for each pen were randomly selected from 5 different chick boxes, group weighed by pen, and then placed on used bedding material top dressed with kiln dried pine shavings. Lighting and temperature control followed industry standards and fans, inlets and heaters were used to maintain optimal growing conditions. Birds were group weighed by pen on days 0, 14, 28, and 41. Feed consumption was measured for each period by weighing all feed added to the pens and any remaining feed at weigh days. Feed was changed from starter to grower at day 14 and from grower feed to finisher feed on day 28. Birds were checked twice daily for mortality and any dead birds were weighed and recorded on a pen sheet and in a log book. Feed conversion was calculated for each period by dividing total feed used by total live weight of the birds in each pen. Mortality weight for each period was added to the pen live weight prior to dividing this combined weight into the feed consumed weight for calculation of an adjusted feed conversion. At day 41, five birds showing no signs of abnormalities including leg disorders were randomly selected, individually weighed, wing banded in both wings and marked with spray paint for easy identification for the following day processing. During the selection process, each bird was individually evaluated for pigmentation coloring of the shanks or legs. A DSM color fan ranging from pale yellow- cream (color 101) to deep orange (color 108) was used for the evaluation and all color evaluations were done by one individual for consistency of measurement. After an 8 hour feed withdrawal, birds were placed in coops and transported to the University of Arkansas processing plant. Birds were again individually weighed, placed on shackles, stunned with an electrical water bath, bled out, scalded, de-feathered, and then eviscerated. During the evisceration process, the leaf fat was carefully removed from the abdominal and gizzard area. The WOG (carcass without giblets) was weighed as well as the fat and then the WOG was placed into an ice bath for a 2 hour chilling process. Next the carcass was removed from the ice bath, re-weighed and then cut into breast meat, tenders, wings and leg quarters. Each part was weighed post cut-up. Yield was determined by dividing the carcass weight by the slaughter weight and multiplying by 100. Percent abdominal fat was calculated as a percent of the slaughter weight. Parts yield was determined as both a percent of the carcass and of the slaughter weight. Results were analyzed using the GLM procedure of SAS and statistically significant means (P<.050 were separated using the repeated t-test). The pen served as the experimental unit for the live production data and the individual bird was the experimental unit for the processing data.

Results:

Average Body Weight and Weight Gain:

The results are shown in Tables 8-12. The birds exhibited similar results to trial one reaching an average weight of around 6.7 lbs at day 41. Results are shown in Table 8 and show that all treatments started with similar average chick weights (~47 grams, P>.05) which helped assure that initial average weights for all pens and treatments were statistically similar. At days 14, 28, and 41, all treatments had similar average weights shown in table 8 (P > .05). Increasing levels of grain sorghum clearly did not inhibit bird consumption of feed and readily supported the genetic growth rate potential. There were no significant differences in the average body weights between treatments at any of the time points (P value for day 0 =.4817, day 14=0.8699, day 28= 0.8152 and day 41=0.4824). There were no difference in average body weight gain for periods days 0-14 (p-value 0.8817), 14-28 (p-value 0.7319), 0-28 (p-value 0.8187), 28-41 (p-value 0.3659), and 0-41 (0.4829) (Table 9.

Feed Conversion and Feed Intake

The feed intake and the unadjusted feed-to-gain ratio were not significantly impacted by increasing levels of grain sorghum but, the adjusted-feed-to-gain ratios using mortality were significantly different at days 28-41 (Tables 10 - 12). However, when feed conversion were adjusted using mortality weight (Table 11), there were differences at day 41 (P=.002). At day 41, the highest or most inefficient feed conversion was seen with the 80% sorghum diet 1.90 and the best or lowest seen with the 20% sorghum diet 1.81 but the 0% sorghum diet was close with its conversion of 1.82 (p-value= 0.0020). In trial 1 the birds were grown to 46 days and the maximum feed conversion was seen at 100% sorghum therefore, this indicates that birds that are not grown as long might have better production growth with a replacement of 20% sorghum instead of 100%.

Livability:

Livability was similar across all treatments ranging from 93.6% to 99.6% and there were no statistical differences between the treatments (Table 13).

Processing:

Yield analysis showed that there were differences in average selection weights (p-value=0.0018) with the 0, 20 and 60% sorghum diets supporting heavier weights than the 40 and 100% sorghum diets. There was a statistical difference in the pre-slaughter weight (P-value = 0.0015) pre-chill weight (p-value= 0.0005) and post-chill weight (p-value= 0.0008) (Table 14) with these following a similar trend to the selection weights. The pre-slaughter weight for the 0% sorghum diets was significantly heavier (2.92Kg) than that of treatment 40 and 100% (2.76, 2.79 kg respectively) sorghum diets did not differ significantly from that of the 20, 60 and 80% sorghum diets (2.90, 2.92, 2.83Kg respectively). For the pre-chill and the post-chill carcass weight, the 60% sorghum diet showed significantly higher weight than the 40 and 100% diets, but did not show any differences compared to the 0, 20 and 80% diets. There was no statistical difference in the average carcass and parts yield. The average parts weight followed the similar trend as in pre-chill and post-chill weights. For breast weight, the 60% sorghum diet (0.572 Kg) weighed more than the 40 and 100% sorghum diets (0.522 and 0.522kg respectively), but did not differ from the 0% (0.560kg), 20% (0.552kg) and 80% (0.542kg) sorghum diets. For tenders, the 20 and 60 % sorghum diets yielded the heaviest (0.115 and 0.115kg respectively) and were heavier than the 100% sorghum diet (0.105kg), but showed no differences compared to the 0

(0.219kg), 40 (0.211kg), or 80% sorghum diets (0.110kg) (P=.0001). No differences were seen in wing weights or percent yield. For percent leg quarters, the 20 and 40% sorghum diets (30.2, 30.2%, respectively) weighed more than the 60 and 80% sorghum diets (29.4, 29.4%, respectively), but there were no differences between other treatments (P=.0330). For abdominal fat weight, the 0 and 40% sorghum diets had the heaviest weights (.046, .046, respectively) with the 80% sorghum diet having the lowest (.039, P=.0362) but there were no other differences among the treatments.

Shank and Carcass Score:

Figure 1 shows the DSM Broiler Fan used for the evaluation of pigmentation of the skin on the shanks (legs) and of the breast skin post processing. The shanks were statistically impacted by the dietary levels of grain sorghum and as levels increased, there was a linear decrease in pigmentation but both diets of 20% sorghum and 40% sorghum had statistically similar values of 103.96 and 103.59.The other values ranged from a high of 105.32 for the 100% corn or 0% sorghum diet to a low of 101.44 for the 100% grain sorghum diet. The color relationship was not as clearly defined for the evaluation of the skin on the breast of processed carcasses prior to chilling with the 100% corn diet having a score of 102.50, 20% sorghum diet having a score of 102.09, the 40%, 60% and 80% grain sorghum dets having similar scores of 102.06, 101.94 and 101.72 and the lowest 100% sorghum diet having a score of 101.66 (P=.0001) (Table 1,7).

Table 1. Composition (g/kg) and calculated nutrient content of broiler starter diets* (0 to 14 d) with different levels of grain sorghum as percentage of total grain component

Ingredient	Grain sorghum % of total grain					
	0 (T_1)	20 (T_2)	40 (T_3)	60 (T_4)	80 (T_5)	100 (T_6)
Yellow corn	645.02	506.18	372.53	243.78	119.70	0.00
Grain sorghum	0.00	126.54	248.35	365.68	478.78	587.86
Soybean meal	304.26	308.17	311.94	315.57	319.06	322.44
Poultry oil	6.52	14.95	23.06	30.87	38.40	45.67
Limestone	11.68	11.58	11.47	11.38	11.28	11.19
Dicalcium phosphate	17.58	17.57	17.57	17.56	17.55	17.55
Salt	5.00	5.00	5.00	5.00	5.00	5.00
DL-Methionine	2.89	3.03	3.17	3.31	3.43	3.56
L-Lysine HCl	3.05	2.95	2.86	2.77	2.69	2.60
L-Threonine	1.25	1.28	1.30	1.33	1.36	1.38
2X vitamin premix[1]	0.25	0.25	0.25	0.25	0.25	0.25
Mintrex P_Se[2]	1.00	1.00	1.00	1.00	1.00	1.00
Choline Cl 60%	1.00	1.00	1.00	1.00	1.00	1.00
Coban 90[3]	0.50	0.50	0.50	0.50	0.50	0.50
TOTAL	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
Calculated analysis						
Crude protein, %	21.20	21.20	21.20	21.20	21.20	21.20
Calcium, %	0.91	0.90	0.90	0.90	0.90	0.90
Nonphytate P, %	0.45	0.45	0.45	0.45	0.45	0.45
ME, kcal/kg	3050.00	3050.00	3050.00	3050.00	3050.00	3050.00
Lysine, %	1.34	1.34	1.34	1.34	1.34	1.34

[1]Provides per kg of diet: vitamin A 7715 IU; cholecalciferol 5511 IU; vitamin E 16.53 IU; vitamin B_{12} 0.013 mcg; riboflavin 6.6 mg; niacin 39 mg; pantothenic acid 10 mg; menadione 1.5 mg; folic acid 0.9 mg; thiamin 1.54 mg; pyridoxine 2.76 mg; d-biotin 0.66 mg; ethoxyquin 125 mg.
[2]Provides per kg of diet: Mn (as manganese methionine hydroxy analogue complex) 40 mg; Zn (as zinc methionine hydroxy analogue complex) 40 mg; Cu (as copper methionine hydroxy analogue complex) 20 mg; Se (as selenium yeast) 0.3 mg. Novus International, St. Louis MO.
[3]Elanco Animal Health Division of Eli Lilly and Co., Indianapolis IN 46825.
*Diets are formulated to meet or exceed standards for high producing males as suggested by Rostagno et al. (2011)

Table 2. Composition (g/kg) and calculated nutrient content of broiler grower diets* (14 to 28 d) with different levels of grain sorghum as percentage of total grain component.

Ingredient	Grain sorghum % of total grain					
	0 (T_1)	20 (T_2)	40 (T_3)	60 (T_4)	80 (T_5)	100 (T_6)
Yellow corn	670.82	526.42	387.41	253.54	124.48	0.00
Grain sorghum	0.00	131.60	258.28	380.30	497.92	611.39
Soybean meal	272.28	276.35	280.27	284.04	287.68	291.18
Poultry oil	17.64	26.41	34.84	42.97	50.80	58.35
Limestone	12.20	12.09	11.99	11.89	11.79	11.69
Dicalcium phosphate	12.43	12.42	12.41	12.40	12.39	12.39
Salt	5.00	5.00	5.00	5.00	5.00	5.00
DL-Methionine	2.75	2.90	3.05	3.18	3.32	3.45
L-Lysine HCl	3.00	2.90	2.81	2.72	2.63	2.54
L-Threonine	1.13	1.16	1.19	1.21	1.24	1.26
2X vitamin premix[1]	0.25	0.25	0.25	0.25	0.25	0.25
Mintrex P_Se[2]	1.00	1.00	1.00	1.00	1.00	1.00
Choline Cl 60%	1.00	1.00	1.00	1.00	1.00	1.00
Coban 90[3]	0.50	0.50	0.50	0.50	0.50	0.50
TOTAL	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
Calculated Analysis						
Crude protein, %	19.80	19.80	19.80	19.80	19.80	19.80
Calcium, %	0.80	0.80	0.80	0.80	0.80	0.80
Nonphytate P, %	0.35	0.35	0.35	0.35	0.35	0.35
ME, kcal/kg	3150.00	3150.00	3150.00	3150.00	3150.00	3150.00
Lysine, %	1.25	1.25	1.25	1.25	1.25	1.25
Methionine, %	0.56	0.57	0.58	0.59	0.60	0.60
TSAA, %	0.91	0.91	0.91	0.91	0.91	0.91
Threonine, %	0.85	0.85	0.85	0.85	0.85	0.85

Provides per kg of diet: vitamin A 7715 IU; cholecalciferol 5511 IU; vitamin E 16.53 IU; vitamin B_{12} 0.013 mcg; riboflavin 6.6 mg; niacin 39 mg; pantothenic acid 10 mg; menadione 1.5 mg; folic acid 0.9 mg; thiamin 1.54 mg; pyridoxine 2.76 mg; d-biotin 0.66 mg; ethoxyquin 125 mg.

[2]Provides per kg of diet: Mn (as manganese methionine hydroxy analogue complex) 40 mg; Zn (as zinc methionine hydroxy analogue complex) 40 mg; Cu (as copper methionine hydroxy analogue complex) 20 mg; Se (as selenium yeast) 0.3 mg. Novus International, St. Louis MO.

[3]Elanco Animal Health Division of Eli Lilly and Co., Indianapolis IN 46825.

Table 3. Composition (g/kg) and calculated nutrient content of broiler finisher diets* (28 to 41 d) with different levels of grain sorghum as percentage of total grain component.

Ingredient	Grain sorghum % of total grain					
	0 (T_1)	20 (T_2)	40 (T_3)	60 (T_4)	80 (T_5)	100 (T_6)
Yellow corn	706.67	554.55	408.13	267.09	131.15	0.00
Grain sorghum	0.00	138.64	272.09	400.63	524.54	644.06
Soybean meal	238.28	242.55	246.69	250.66	254.50	258.19
Poultry oil	19.29	28.52	37.40	45.96	54.21	62.17
Limestone	11.18	11.07	10.96	10.85	10.74	10.65
Dicalcium phosphate	9.94	9.94	9.93	9.92	9.91	9.90
Salt	5.00	5.00	5.00	5.00	5.00	5.00
DL-Methionine	2.53	2.69	2.84	2.99	3.13	3.27
L-Lysine HCl	3.22	3.12	3.01	2.92	2.82	2.73
L-Threonine	1.14	1.17	1.20	1.23	1.25	1.28
2X vitamin premix[1]	0.25	0.25	0.25	0.25	0.25	0.25
Mintrex P_Se[2]	1.00	1.00	1.00	1.00	1.00	1.00
Choline Cl 60%	1.00	1.00	1.00	1.00	1.00	1.00
Coban 60[3]	0.50	0.50	0.50	0.50	0.50	0.50
TOTAL	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
Calculated Analysis						
Crude protein, %	18.40	18.40	18.40	18.40	18.40	18.40
Calcium, %	0.70	0.70	0.70	0.70	0.70	0.70
Nonphytate P, %	0.30	0.30	0.30	0.30	0.30	0.30
ME, kcal/kg	3200.00	3200.00	3200.00	3200.00	3200.00	3200.00
Lysine, %	1.17	1.17	1.17	1.17	1.17	1.17
Methionine, %	0.53	0.53	0.54	0.55	0.56	0.57
TSAA, %	0.85	0.85	0.85	0.85	0.85	0.85
Threonine, %	0.80	0.80	0.80	0.80	0.80	0.80

[1]Provides per kg of diet: vitamin A 7715 IU; cholecalciferol 5511 IU; vitamin E 16.53 IU; vitamin B_{12} 0.013 mcg; riboflavin 6.6 mg; niacin 39 mg; pantothenic acid 10 mg; menadione 1.5 mg; folic acid 0.9 mg; thiamin 1.54 mg; pyridoxine 2.76 mg; d-biotin 0.66 mg; ethoxyquin 125 mg.
[2]Provides per kg of diet: Mn (as manganese methionine hydroxy analogue complex) 40 mg; Zn (as zinc methionine hydroxy analogue complex) 40 mg; Cu (as copper methionine hydroxy analogue complex) 20 mg; Se (as selenium yeast) 0.3 mg. Novus International, St. Louis MO.
[3]Elanco Animal Health Division of Eli Lilly and Co., Indianapolis IN 46825.
*Diets are formulated to meet or exceed standards for high producing males as suggested by Rostagno et al. (2011).

Table 4. Analyzed nutrient composition of starter diets (0-14 d of age)

	Dietary Treatments					
	T_1	T_2	T_3	T_4	T_5	T_6
	-------------------------------------(%)---------------------------------					
	Analyzed Nutrient Composition					
Moisture (%)	11.2	10.9	11.1	11.4	11.4	11.3
Crude Protein (%)	21.3	21.1	21.6	23.4	21.7	20.9
Crude Fat (%)	3.37	5.10	4.73	5.62	5.03	3.23
Ash (%)	5.30	5.92	5.38	5.36	5.50	5.86

Table 5. Analyzed nutrient composition of grower diets (14-28 d of age)

	Dietary Treatments					
	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**
	------------------------------------(%)--------------------------------					
	Analyzed Nutrient Composition					
Moisture (%)	11.5	11.4	11.3	11.5	11.1	11.3
Crude Protein (%)	20.6	19.2	20.3	20.6	21.3	21.2
Crude Fat (%)	4.57	5.27	5.75	7.13	6.37	8.07
Ash (%)	5.26	4.99	5.09	5.26	4.85	5.15

Table 6. Analyzed nutrient composition of finisher diets (28-41 d of age)

	Dietary Treatments					
	T_1	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**
	----------(%)----------					
	Analyzed Nutrient Composition					
Moisture (%)	11.2	11.1	11.2	10.9	11.6	11.8
Crude Protein (%)	19.2	17.8	20.1	19.4	17.6	19.4
Crude Fat (%)	5.46	5.21	6.97	7.98	8.36	8.94
Ash (%)	4.87	4.48	4.80	4.87	4.70	4.75

Table 7. Experimental design of treatments and number of replications and birds

Treatment	Corn (%)	Milo (%)	No. of pens/trt	No. of birds/pen
1	100	0	10	25
2	80	20	10	25
3	60	40	10	25
4	40	60	10	25
5	20	80	10	25
6	0	100	10	25

Table 8. Average body weight (Mean ± SEM) of male broilers fed different dietary levels of milo/sorghum*

Trt	Day 0	Day 14	Day 28	Day 41
		---------------------------kg---------------------------		
1-Corn	.0477 ± 0.19	0.464 ± 0.007	1.586 ± 0.024	2.907 ± 0.029
2-20% Sorghum	.0476 ± 0.21	0.465 ± 0.006	1.561 ± 0.007	2.883 ± 0.038
3-40% Sorghum	.0472 ± 0.16	0.455 ± 0.009	1.559 ± 0.018	2.851 ± 0.030
4-60% Sorghum	.0474 ± 0.22	0.459 ± 0.008	1.579 ± 0.020	2.870 ± 0.040
5-80% Sorghum	.0476 ± 0.16	0.462 ± 0.006	1.578 ± 0.014	2.820 ± 0.045
6-100% Sorghum	.0476 ± 0.17	0.456 ± 0.005	1.562 ± 0.012	2.820 ± 0.037
P-value	0.4817	0.8699	0.8152	0.4824

*Means within a column with no common superscript differ significantly ($P < 0.05$).

Table 9. Average body weight gain (Mean ± SEM) of male broilers grown to 41 days of age and fed different dietary levels milo/sorghum

Trt	**Day 0-14**	**Day 14-28**	**Day 0-28**	**Day 28-41**	**Day 0-41**
		--------------------------kg--------------------			
1-Corn	0.41 ± 0.007	1.12 ± 0.023	1.54 ± 0.024	1.32 ± 0.019	2.86 ± 0.029
2-20% Sorghum	0.42 ± 0.006	1.10 ± 0.005	1.51 ± 0.007	1.32 ± 0.034	2.84 ± 0.038
3 40% Sorghum	0.41 ± 0.009	1.10 ± 0.013	1.51± 0.018	1.29 ± 0.027	2.80 ± 0.030
4-60% Sorghum	0.41± 0.008	1.12 ± 0.014	1.53 ± 0.020	1.29 ± 0.027	2.82 ± 0.040
5-80% Sorghum	0.42 ± 0.06	1.12 ± 0.011	1.53 ± 0.014	1.24 ± 0.042	2.77 ± 0.045
6-100% Sorghum	0.42 ± 0.005	1.12± 0.009	1.52 ± 0.012	1.26 ± 0.031	2.77 ± 0.037
P-value	0.8817	0.7319	0.8187	0.3659	0.4829

Table 10. Un-adjusted FCR (Mean ± SEM) of male broilers grown to 41 days of age and fed different dietary levels of milo/sorghum

Trt	Day 0-14	Day 0-28	Day 14-28	Day 0-41	Day 28-41
			--------------------------------kg:kg --------------------------		
1-Corn	1.36±0.017	1.62±0.015	1.55±0.01	1.67± 0.002	1.82b ± 0.007
2-20% Sorghum	1.38±0.017	1.63±0.015	1.56±0.01	1.67± 0.002	1.81b ± 0.007
3-40% Sorghum	1.35±0.017	1.60±0.015	1.53±0.01	1.67± 0.002	1.83b ± 0.007
4-60% Sorghum	1.40±0.017	1.59±0.015	1.54±0.01	1.68± 0.002	1.84b ± 0.007
5-80% Sorghum	1.37±0.017	1.59±0.015	1.53±0.01	1.69± 0.002	1.90a ± 0.007
6-100% Sorghum	1.38±0.017	1.58±0.015	1.52±0.01	1.69± 0.002	1.89a ± 0.007
P-value	0.485	0.3284	0.1840	0.2320	0.0020

*Means within a column with no common superscript differ significantly ($P < 0.05$).

Table 11. Adjusted feed conversion (Mean ± SEM) of male broilers grown to 41 days of age and fed different dietary levels of milo/sorghum

Trt	Day 0-14	Day 14-28	Day 0-28	Day 28-41	Day 0-41
			-----------------------------kg:kg------------------------------		
1-Corn	1.39± 0.02	1.63 ± 0.016	1.56 ± 0.013	1.88 ± 0.03	1.70 ± 0.014
2-20% Sorghum	1.38 ± 0.02	1.63 ± 0.016	1.56 ± 0.013	1.90 ± 0.03	1.71 ± 0.014
3-40% Sorghum	1.36 ± 0.02	1.60 ± 0.016	1.54 ± 0.013	1.87 ± 0.03	1.68 ± 0.014
4-60% Sorghum	1.41± 0.02	1.59 ± 0.016	1.54 ± 0.013	1.87 ± 0.03	1.69 ± 0.014
5-80% Sorghum	1.38 ± 0.02	1.61 ± 0.016	1.55 ± 0.013	1.90 ± 0.03	1.70 ± 0.014
6-100% Sorghum	1.38± 0.02	1.58 ± 0.016	1.52 ± 0.013	1.95 ± 0.03	1.71 ± 0.014
P-value	0.6094	0.1840	0.3294	0.5591	0.7308

*FCR is adjusted for mortality.

Table 12. Adjusted feed intake (Mean ± SEM) of male broiler grown to 41 days of age and fed different dietary levels of milo/ sorghum

Trt	**Day 0-14**	**Day 14-28**	**Day 0-28**	**Day 28-41**	**Day 0-41**
			-------------------------------kg:kg-----------------------		
1-Corn	.569 ± .009	1.831 ± .019	2.388± .025	2.408 ± .04	4.794 ± .06
2-20% Grain Sorghum	.577 ± .009	1.792 ± .019	2.369 ± .025	2.389 ± .04	4.758 ± .06
3-40% Grain Sorghum	.551 ± .009	1.775 ± .019	2.325 ± .025	2.366 ± .04	4.691 ± .06
4-60% Grain Sorghum	.578 ± .009	1.784 ± .019	2.361 ± .025	2.385 ± .04	4.745 ± .06
5-80% Grain Sorghum	.570 ± .009	1.780 ± .019	2.349 ± .025	2.354 ± .04	4.702 ± .06
6-100% Grain Sorghum	.563 ± .009	1.748 ± .019	2.311 ± .025	2.381 ± .04	4689 ± .06
P-value	0.2834	0.2353	0.3142	0.9660	0.8236

Table 13. Impact of increasing dietary levels of grain sorghum on livability of male broilers fed to 41 days of age

Trt	Days 0-14	Days 0-28	Days 0-41
		----------------------------%-----------------------	
1-Corn	96.4 ± 1.26	95.2 ± 1.55	93.6 ± 2.17
2-20% Sorghum	99.6 ± 0.40	99.6 ± 0.40	97.6 ± 0.88
3-40% Sorghum	98.4 ± 0.65	98.4 ± .0.65	97.6 ± 0.88
4-60% Sorghum	98.0 ± 1.23	98.0 ± 1.23	97.2 ± 1.58
5-80% Sorghum	97.2 ± 0.85	96.0 ± 1.19	96.0 ± 1.19
6-100% Sorghum	99.2 ± 0.53	98.8 ± 0.61	97.2 ± 1.04
P-value	0.0153	0.1178	0.2847

Table 14. Average processing weights (Mean ± SEM) of 41 day old male broilers fed different dietary levels of Sorghum/Milo*

Trt	Selection Weight	Pre-Slaughter Weight	Pre-chill WOG Weight	Post-chill WOG Weight
		----------------------------**kg**----------------------------		
1-Corn Diet	2.92a ± 0.03	2.99^{a} ± 0.05	2.11^{a} ± 0.02	2.15^{ab} ± 0.02
2-20% Sorghum	2.91a ± 0.03	2.90^{abc} ± 0.04	2.09^{ab} ± 0.03	2.14^{abc} ± 0.03
3-40% Sorghum	2.81b ± 0.04	2.76^{c} ± 0.03	2.00^{b} ± 0.02	2.04^{c} ± 0.03
4-60% Sorghum	2.92a ± 0.03	2.92^{ab} ± 0.04	2.11^{a} ± 0.03	2.16^{a} ± 0.03
5-80% Sorghum	2.84ab ± 0.03	2.83^{abc} ± 0.03	2.04^{ab} ± 0.02	2.09^{abc} ± 0.02
6-100% Sorghum	2.80b ±0.03	2.79^{bc} ± 0.03	2.00^{b} ± 0.03	2.05^{bc} ± 0.02
P-value	.0153	0.0015	0.0005	0.0008

*Means within a column with no common superscript differ significantly ($P < 0.05$).

Table 15. Average carcass and parts yield (Mean ± SEM) of 41 day old male broilers fed different dietary levels of Sorghum/Milo

Trt	Fat	Carcass	Breast	Tenders	Wings	Legs
------------------------------------%-------------------------------						
1-Corn	2.14 ± 0.08	73.1 ± 0.76	26.0± 0.34	5.2± 0.07	10.2± 0.07	29.9ab±0.2
2- 20% Sorghum	2.10 ± 0.08	73.9 ± 0.40	25.7 ± 0.24	5.4 ± 0.06	10.2 ± 0.07	30.2a ± 0.2
3-40% Sorghum	2.25 ± 0.08	73.9 ± 0.23	25.5 ± 0.26	5.4 ± 0.07	10.3 ± 0.06	30.2a ± 0.2
4- 60% Sorghum	2.07± 0.08	74.2 ± 0.49	26.4 ± 0.30	5.3 ± 0.08	10.3 ± 0.10	29.4b± 0.2
5- 80% Sorghum	1.88 ± 0.08	73.9 ± 0.35	25.9 ± 0.29	5.2 ± 0.07	10.2 ± 0.07	29.4b ± 0.2
6- 100% Sorghum	2.14 ± 0.09	73.8 ± 0.34	25.4 ± 0.37	5.1 ± 0.08	10.8 ± 0.08	29.9ab±0.2
P-value	0.0649	0.7035	0.2290	0.183	0.7650	0.0330

Table 16. Average parts weight (Mean ± SEM) of 41 day old male broilers fed different dietary levels of Sorghum/Milo

Trt	**Breast Weight**	**Tenders Weight**	**Wings Weight**	**Legs Weight**	**Abdominal Fat Weight**
		-----------------------------------kg	**-------------------------------**		
1-Corn	.560^{ab} ± .011	.112^{ab} ± .002	.219 ± .002	.642 ± .007	.046a± .001
2- 20% Sorghum	.552^{ab} ± .010	.115^{a} ± .002	.217 ± .002	.645 ± .008	.045ab ± .001
3-40% Sorghum	.522^{b} ± .09.33	.109^{ab} ± .001	.211 ± .002	.616 ± .008.22	.046a±.001
4- 60% Sorghum	.572^{a} ± .011	.115^{a} ± .002	.221± .002	.633 ± .006	.044ab ± .001
5- 80% Sorghum	.543^{ab} ± .009	.110^{ab} ± .001	.213 ± .002	.613 ± .007	.039b±.001
6- 100% Sorghum	.522^{b} ± .010	.105^{b} ± .001	.210 ± .002	.612 ± .008	.044ab± .001
P-value	0.0068	0.0001	0.6118	0.4388	0.0362

*Means within a column with no common superscript differ significantly ($P < 0.05$).

Table 17. Average shank color score and carcass color score (Mean ± SEM) of 41 day old male broilers fed different dietary levels of Sorghum/Milo

Treatment	Shank Color Score	Carcass Color Score
1-Corn Diet	$105.32^{a} \pm 0.12$	$102.50^{a} \pm 0.12$
2-20% Grain Sorghum	$103.96^{b} \pm 0.11$	$102.09^{ab} \pm 0.10$
3-40%Grain Sorghum	$103.59^{b} \pm 0.11$	$102.06^{bc} \pm 0.10$
4-60% Grain Sorghum	$102.84^{c} \pm 0.11$	$101.94^{bc} \pm 0.10$
5-80% Grain Sorghum	$102.04^{d} \pm 0.10$	$101.72^{bc} \pm 0.10$
6-100% Grain Sorghum	$101.44^{e} \pm 0.09$	$101.66^{c} \pm 0.10$
P-value	<0.0001	<0.0001

*Means within a column with no common superscript differ significantly ($P < 0.05$)

Figure 1. DSM Broiler Fan utilized for evaluation of shank (live bird legs) and breast skin (post processing) pigmentation.

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Discussion for Trial 1 and 2

There have been several studies conducted on grain sorghum and its performance on broiler chicken over the years. In a study conducted by Torres et al. in 2013, 594 male Cobb-500 broilers were reared to 42 days on a combination of corn-soybean or low-tannin sorghum based diets. They implemented 3 treatments at 100% corn, 50% corn and 100% sorghum with 66 replicates and 33 birds in 18 pens. The temperature was at industry settings and they provided 24 hour lighting. At days 7, 21 and 42 they measure body weight gain, feed consumption and feed conversion. At day 42 the 50% corn/sorghum diet had the highest feed intake, highest weight gain and the lowest or most efficient feed conversion but, the 100% sorghum diet had the lowest feed intake, lowest weight gain and highest or most inefficient feed conversion. . Another trial conducted by Ahmed et. al., in 2013 reared 140 day old unsexed Ross broilers to 42 days with a combination diet of corn and groundcake or sorghum and groundcake. It had five treatments consisting of 100% sorghum, 75% sorghum, 50% sorghum, 25% sorghum and 100% corn with four replicates and 28 birds in seven pens. They took measurements of feed intake and body weight gain at day 42. The 100% sorghum diet had the highest feed intake, 75% sorghum diet had the highest weight gain and poorest or least efficient feed conversion and the 100% corn diet had the most efficient feed conversion. These results were very similar to the results found in the two trials that were conducted in this research

In the trials that were conducted for this research the highest feed intake was exhibited by the 100% corn diet, the highest weight gain was shown in the 80% and 100% sorghum diets but, the best feed conversion was seen in the 80% sorghum diet. The worst feed conversion was seen in the 100% sorghum diet. After the amount of sorghum in the diet passed 80% sorghum the birds seem to have negative returns. In both trials the unadjusted feed conversion and feed intake were not statically impacted and readily supported the genetic growth rate potential. However, feed conversion did increase at the higher levels of dietary sorghum which indicates estimation of dietary energy may be overestimated, particularly for the last dietary period of 28-46 or 41 days which would be during in the time when the birds would require the highest energy levels of the three dietary periods.

While shank and breast meat coloring had a linear decline with the increasing sorghum levels in both trials, this should pose little concern for the US producers since only 10% of chickens in the US are sold as whole birds and the majority of the chicken meat market targets value added further processed products with boneless skinless breast meant and tenders bringing the premium price. Therefore, the loss of pigmentation in a diet high in sorghum would have a significant impact on North American consumers is unlikely. However, in other countries like Mexico, the whole bird market is very popular. In addition, consumers prefer a much more yellow bird and will not purchase the product unless it has a deep yellow pigment. Therefore, in these industries sorghum would rarely be an option as an ingredient in the broiler industry unless, the birds were fed a supplement that increased the skin pigmentation.

Conclusion

With corn becoming more expensive, it is important to explore alternative cereal grains like grain sorghum. Traditionally, sorghum has not been a popular feed ingredient due to the tannin content which had anti-nutritional factors as well as added a bitter taste to the feed. Now that low- tannin grain sorghum can be produced on a commercial scale, particularly in arid climates with limited water supplies, it may become possible to grow adequate quantities to support some of the needs of the poultry industry. If grain sorghum can become an alternative to corn then cost of broiler meat production in areas such as Africa could be greatly reduced.

The results from both studies suggest that grain sorghum can replace up to 80% of the corn in commercial broiler diets without impacting weight gains, feed intake, livability and yield. While 60 and 80% replacement supported feed conversions similar to the diets with corn as the primary cereal grain, the 100% grain sorghum diets did increase the adjusted feed conversion for the 28-41 day period which indicates additional research may be needed to determine how the available energy content actually compares to that of corn.

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